Whispering gallery mode oscillators and optical comb generators

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Ultrastable optical resonators play an important role in both classical and quantum optics and generally are of Fabry-Perot (FP) type. They are fabricated from materials having ultra low thermal expansion coefficients, and are both thermally and mechanically isolated to achieve stability. The geometrical dimensions of this type of resonators is typically about 10 cm or larger. Whispering gallery mode (WGM) optical resonators are attractive for frequency stabilization of lasers and realization of frequency references, especially where size or miniaturization matters. Fabrication and handling of WGM resonators is relatively simple, and efficient light coupling techniques have been developed for these resonators. Furthermore, the spectra of WGMs can be modified by changing the morphology of resonators. Recently, crystalline WGM resonators with finesse exceeding 10^7 have been demonstrated, and various methods of active and passive frequency stabilization have also been developed for these compact devices.

In this paper we discuss an approach for generating microwave and mm-wave signals at any desired frequency using four-wave mixing process in a nonlinear crystalline WGM resonator. We show that cw light results in four-photon processes that generate optical sidebands around the optical carrier in a high finesse WGMs. Cascading of the process and generating stable optical combs is also. Demodulation of the output of the device by means of a fast photodiode results in the generation of high frequency microwave and mm-wave signals, the frequency of which is determined by the size of the resonator. The spectral purity of the signal increases with increasing quality (Q) factor of the modes and the optical power of the generated sidebands. The pumping threshold of the oscillation can be in a few microWatt range for resonators with ultra-high Q.

In particular, we will report on the experimental demonstration of a tunable monolithic optical frequency comb generator as a source of spectrally pure mm-wave reference signals. The device is based on the hyper-parametric oscillations in a crystalline CaF_2 WGM resonator. The frequency spacing of the comb is given by an integer number of the free spectral ranges of the resonator and is *~25xm GHZ* (*m* is an integer number). We select the desired number by tuning the pumping laser frequency with respect to the corresponding resonator mode. We also observe interacting optical combs and high-frequency hyperparametric oscillation, depending on the experimental conditions. The spectral width of the comb exceeds 30 THz.

Generation of microwave and mm-wave signals at the comb repetition frequency is a consequence, and indeed an indication, that the comb lines are coherent. The spectral purity of the signal increases with increasing Q factor of the WGMs, the optical power of the generated sidebands, and the spectral width of the comb. In our experiments 25 GHz signals exhibit less than 40 Hz linewidth; this value is limited by our measurement set-up.